1 Measurement of Beam-Spin Azimuthal Asymmetries in Pion Electroproduction at HERMES

Nature's building blocks - elementary particles, their characteristics and interactions are described by the Standard Model. According to this model there are 6 flavors of quarks (**u,d,s,c,b,t**) and their corresponding antiquarks, and similarly 6 leptons - 3 charged (e,μ,τ) and 3 neutral (ν_e,ν_μ,ν_τ) and their corresponding antileptons. Quarks participate in the electroweak interactions like leptons do, yet, in addition they interact strongly by exchanging gluons. A new type of charge has been introduced to describe the strong interaction - the *COLOR*, which is described by Quantum Chromodynamics (QCD).

While the quark contents of the nucleon have been measured with high precision in many Deep Inelastic Scattering (DIS) experiments, the distributions of the quark spin and angular momentum are still a matter of intensive investigations. In contraty to the very naïve model expectations it was experimentally shown that the spins of the valence quarks do not sum up to $\frac{1}{2}$ - the spin of a nucleon, but only less then 30% of it, which is often referred to as the *Spin Puzzle*. Later measurements have fixed this number at only $(33 \pm 4)\%$, which is way too small compared to the predictions of $\sim 60\%$ based on relativistic models of the proton. The missing portion of the spin is presumably carried by the gluons, virtual quark-antiquark pairs (sea quarks) and the orbital angular momentum of all nucleon constituents. Since the fact that the coupling constant of the strong force is not a true constant but changes its value depending on the scale of the interaction Q^2 - the square of the virtual photon 4-momentum , the perturbative methods of QCD calculations do not work at low energies, where the coupling constant is large. Therefore the description of the nucleon structure, in particular its spin structure, is impossible in perturbative QCD.

Experiments are important tools to study the structure and individual contributions to the spin of the nucleon. These contributions are described by a variety of phenomenological polarised structure functions which tell the distribution of the spin inside the nucleon. Some of these structure functions have been studied at the HERMES experiment, using the 27.6GeV electrons of the HERA accelerator at the DESY laboratory in Hamburg, in deep inelastic scattering off a nucleon.

Since the measured cross sections depend on an impractically large number of kinematic variables, some of these are integrated out. This reduces the set of observables to three distribution functions: the quark density, helicity and transversity distributions, which were the subject of intensive study up to now. The recent introduction of the transverse momentum dependent (TMD) distribution function, which is related to the overlap of wave functions with different orbital momenta opens a new avenue for more detailed studies of the orbital motion of quarks.

These functions can be accessed in the semi-inclusive DIS (SIDIS) where in addition to the scattered lepton a produced hadron is detected. The amplitude of this process can be factorized as a convolution of a distribution function (DF), a hard scattering amplitude for scattering of a lepton off a point-like quark, and a fragmentation function (FF) describing the transition of a quark to a hadron of a given type.

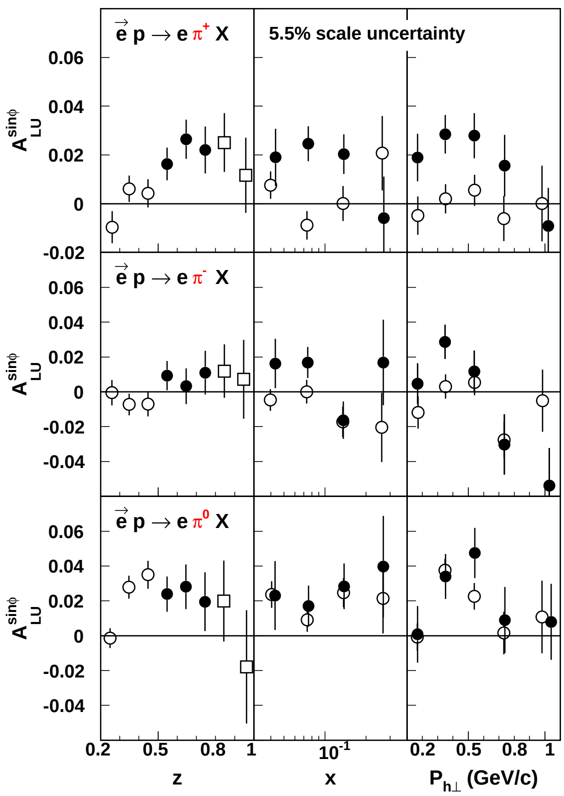

Figure 1: Dependence of the beam SSA on z, x, and $P_{h\perp}$. The error bars represent the statistical uncertainty. An additional 5.5% fractional scale uncertainty is due to the systematic uncertainty in the beam polarization measurement. Total systematic uncertainties do not exceed 0.005 (0.007 for π^0).

A well-suited observable in such measurements that allows to study the polarisation and orbital motion of the quarks inside a nucleon, is a single-spin asymmetry (SSA) in the scattering cross-section depending on the orientations of the spins of the interacting particles.

In the particular case of a polarized beam and unpolarized target, six combinations of distribution and fragmentation functions contribute to the polarized cross-section. The total azimuthal asymmetry amplitude turns out to be suppressed by $1/Q$, hence such a measurement is possible only at moderate values of Q^2, accessible at HERMES.

In the present measurement the beam-spin azimuthal asymmetry is extracted for charged and neutral pions using data taken with a longitudinally polarized beam (L), the hydrogen target being (considered) unpolarized (U). The most relevant amplitudes of these asymmetries, $A_{LU}^{\sin\phi}$, are shown in Fig. 1 as functions of pion fractional energy z, Bjorken scaling variable x, and the pion transverse momentum $P_{h\perp}$. Three regions in z are considered: the low-z ($0.2 < z < 0.5$), the mid-z ($0.5 < z < 0.8$), and the high-z region ($0.8 < z < 1$). The x and $P_{h\perp}$ distributions of $A_{LU}^{\sin\phi}$ are extracted for the low- and mid-z regions separately and presented as open and full circles, respectively.

The measured asymmetry amplitudes for π^+ mesons are positive of the order of 0.02 in the mid-z region, which is an evidence for sizeable TMD DFs. Similarly, the $P_{h\perp}$ dependences of $A_{LU}^{\sin\phi}$ for all pions exhibit a clear bump at $P_{h\perp} \approx 0.5$ GeV which agrees well with the expectations of theory that predicts nonzero TMD DFs only for moderate values of $P_{h\perp}$.

A future global analysis of beam SSAs combined with SSAs with longitudinally and transversely polarised targets, as well as jet asymmetries if available, will allow a more complete understanding of the nucleon spin structure as well as of the underlying mechanisms of quark fragmentation.